Appendix B- Acid Deposition and Air Quality

Air Quality

Current Conditions

Acid deposition occurs when acidic sulfur- and nitrogen- containing compounds in the atmosphere are deposited on the earth's surface through rain, clouds, snow, fog, or as dry particles. These acidic inputs can contribute to degradation of stream water quality and decrease the amount of available base cations in the soil substrate. As described in the soils section, an ecosystem's susceptibility to soil nutrient losses and decreases in stream water acid neutralizing capacity (ANC) are influenced by many factors; most notably the bedrock geology/lithology types, physical characteristics of the soil and the level of acidic inputs. Soil chemistry data from the Lower Williams Project Area (LWPA) demonstrate increased risk for susceptibility to these negative effects of acidic deposition. Additionally, stream chemistry measurements from the LWPA corroborate with the findings from the soils data (See Soils Section in the document). Sulfur dioxide (SO_2) and nitrogen oxide (NO_x) emissions, primarily from fossil fuel combustion, constitute the major anthropogenic pollutants contributing to acidic deposition in the eastern United States. These same pollutants, largely sulfate in the eastern U.S., also contribute to visibility impairment. Roughly 67% of the total SO_2 emissions and 22% of the total NO_x emissions in the U.S. can be attributed to the electric power generation sector (EPA, 2005). Pennsylvania and Ohio, two of the three states with the highest SO_2 emissions in the U.S. are directly north to north west (primarily upwind) of West Virginia.

Concern over the ecological impacts in North America due to acidic deposition became prevalent in the 1960s and 1970s (Driscoll et al. 2001). In response to continued concerns over documented impacts to surface waters, Congress passed Title IV of the 1990 Clean Air Act Amendments and the EPA subsequently promulgated the Acid Rain Program (ARP). The ARP was implemented in two Phases, with Phase I reductions occurring in 1995 and Phase II beginning in 2000. As of 2005, the eleventh year of implementation, national emissions of SO_2 decreased by 41% from 1980 levels and 35% from 1990 levels. The most recent ARP Progress Report found that emission reductions were the greatest in states where emissions are the highest, particularly those containing top emitters located along the Ohio River Valley. Among these, Ohio achieved a 42% reduction and Pennsylvania achieved 24% reduction. (EPA, 2005) Additionally, this Progress Report found that West Virginia SO_2 emissions decreased by 45%. However, an analysis of emissions data from 1995 to the present for West Virginia, available through the Clean Air Markets Division Acid Rain database (website), shows that these large reductions occurred at several facilities (due to installation of air pollution controls), while other large coal burning power plants have either maintained or slightly increased their emissions over 1995 levels (air quality specialist, GIS analysis & professional knowledge). This is shown in figure 1. Additional reductions for the remaining plants are expected under the Clean Air Interstate Rule (CAIR) and the WV State Implementation Plan for the Regional Haze Rule. (Information provided by WV DEP staff under regional haze consultation.)

SO$_2$ emissions reductions are reflected in the data from monitoring networks established to track geographic and temporal trends in acid deposition. Analyses of acid precipitation chemistry from an eleven-year period have shown concurrent reductions in precipitation sulfate concentrations since 1983, with marked reductions occurring after implementation of Phase I of the ARP. These reductions, many of which are statistically significant, have been greatest in the Ohio River Valley and the northern portion of the Mid-Atlantic region. The data also reflect almost identical reductions in hydrogen ion concentrations in precipitation, although the statistical significance levels are not as high as those for sulfate.

Though not as dramatic as SO$_2$ emission reductions, NOx emissions have been reduced by 3.3 million tons from 1990 levels due to mandates under the ARP as well as a suite of other regulatory efforts aimed at NO$_x$ reduction (EPA, 2005). However, analogous trends for nitrate have not been observed in precipitation chemistry, with almost as many sites exhibiting increasing concentrations as those with decreasing concentrations. Additionally, atmospheric deposition of base cations appears to be decreasing. Thus, while sulfate and hydrogen ion concentrations in precipitation chemistry are decreasing, the associated decreases in base cations, which play a role in neutralizing acidity, along with relatively unchanged nitrate concentrations may be confounding decreases in the free acidity of precipitation chemistry (Lynch et al. 1997, EPA 2005).

While emission reductions under Title IV of the Clean Air Act, along with associated decreases in acid deposition have been substantial, the 2005 National Acid Precipitation Assessment Program (NAPAP) Report noted that additional reductions in emissions of 40 to 80 percent beyond those already achieved by Phase I and Phase II of the ARP are necessary to restore many sensitive acidified ecosystems (NAPAP, 2005; Driscoll et al. 2001). Further, this Report found that currently there is no research indicating recovery of forested ecosystems in North America affected by acid deposition is occurring. This finding may be applicable for many locations on the Monongahela National Forest, as demonstrated through stream and soil chemistry data as well as MAGIC modeling results.

Current Condition Assessment
The intent of this assessment is to evaluate the current conditions related to air quality and acidic deposition for the LWPA in the context of projected future emission scenarios and previously modeled aquatic ecosystem response to acidic deposition. This analysis focuses on sulfur and sulfate deposition as the primary source of anthropogenic acidification in the project area. While nitrogen-containing compounds also can result in acidifying ecosystems, sulfates are likely to remain the dominant contributor to acidification in the eastern U.S. in the near term. As sulfate deposition continues to decrease in the future, the role of nitrates in both short- and long-term acidification will become more prominent (NAPAP, 2005).

Methods & Data
Several steps were necessary in order to evaluate the existing condition and the projected future condition as they relate to acidic inputs. First, it was necessary to develop estimates of total deposition of sulfate (kg/ha/yr) for the LWPA. Second, projections of future acid deposition inputs based on anticipated reductions under current air quality rules and regulations were needed. Finally, these estimates of total deposition for current and future year scenarios were

evaluated using results from aquatic ecosystem response modeling conducted for streams on the MNF. Details on the methodology for each of these steps are provided in this section. Datasets and modeling projections utilized in this evaluation include:

1. The VISTAS RPO CMAQ[1] modeling deposition outputs for both wet and dry components that were modeled using the base G 2002 base year and the 2018 out year emissions inventories;
2. Deposition monitoring data from the National Atmospheric Deposition Program (NADP) and Clean Air Status and Trends Network (CASTNET) monitoring sites located closest to the LWPA;
3. Spatially contiguous wet deposition data files that were interpolated by accounting for topographic and meteorological influences (Grimm & Lynch 1997);
4. MAGIC modeling outputs for steams within the LWPA.

Estimates of Total Sulfur Deposition

Available raster files (GIS datasets) of annual wet deposition values, averaged for a six year period, 1995 – 2000, were used as a base deposition layer. These datasets, developed by Grimm and Lynch, spatially interpolate wet deposition data between monitoring sites by accounting for the influences of elevation and precipitation/meteorological conditions on deposition patterns. Since deposition is spatially variable and highly dependent on these meteorological and topographic factors, the Grimm and Lynch datasets are likely more appropriate for assessing spatial distribution of deposition than data that are spatially interpolated using inverse distance weighted methods, or deposition amounts calculated from an emissions dispersion model. Further information on the methods used to develop this data is published in Grimm and Lynch (1997). Additionally, wet deposition varies annually due to variation in precipitation patterns from year to year. The average deposition for a six year period was calculated to address this annual variability. Despite the shorter averaging period, it is more appropriate to start with 1995 rather than 1989, because this time period correlates with implementation of Phase I of the ARP. Including data for years prior to 1995 may artificially increase the base year deposition estimates. Figure 1 shows the range of wet sulfate deposition values used as the base deposition data layer for the LWPA.

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[1] Community Multi-Scale Air Quality Model

Figure 1: Averaged wet sulfate deposition estimates from 1995-2000 from Grimm & Lynch (1997).
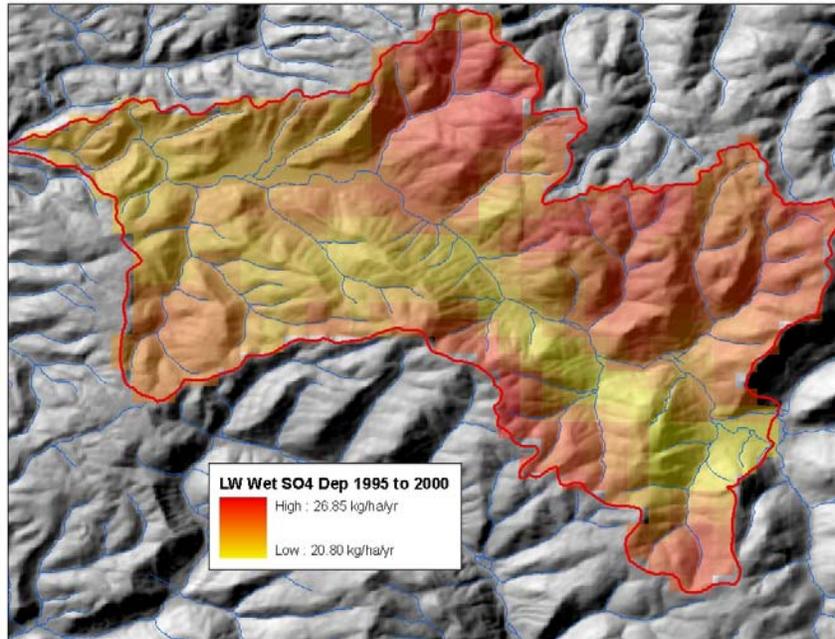
Because the Grimm and Lynch data only represent the wet component of sulfate deposition, it was necessary to estimate total (wet + dry) deposition using these values as a base and applying scaling factors. A range of scaling factors determined to be appropriate for the LWPA were developed using a two-part exercise. This analysis did not account for estimates of cloud water deposition, which may occur with greater frequency in the higher elevations. First, the ratios of dry to total deposition based on the actual deposition monitoring data were calculated. There are two monitoring sites relatively close to the LWPA that participate in both the National Atmospheric Deposition Program (NADP) for wet deposition monitoring and the Clean Air Status and Trends Network (CASTNET) for dry deposition. These are the Cedar Creek State Park site, operated by United States Environmental Protection Agency (USEPA), and the Parsons site, operated by the US Forest Service, Northeastern Research Station. Ratios of dry to total deposition of sulfur for all years with a complete dataset from both NADP and CASTNET monitors for 1989 through 2003 were calculated for Parsons and Cedar Creek. An average ratio of years with complete datasets was calculated for each site. This analysis showed that for the 11 monitoring years at the Parsons site, the average ratio of dry to total deposition is 0.42 (Table 1), or otherwise stated, dry deposition comprises 42% of the total deposition at the Parsons site. For the Cedar Creek site this ratio is somewhat lower -- 27% of the total deposition (Table 2).

Table 1: Ratios of dry to total deposition from available monitored deposition data at the Parsons site for 1989-2003. *Source: CASTNET/NADP-NTN data for Parsons.*

Year	Dry Dep CASTNET (S kg/ha/yr)	Total Dep CASTNET/NADP (S kg/ha/yr)	Ratio
1989	9	23	0.39
1990	9	20	0.45
1991	7	17	0.41
1992	8	17	0.47
1995	5	12	0.42
1997	6	13	0.42
1998	6	15	0.37
1999	4	10	0.40
2000	6	12	0.50
2002	4	11	0.36
2003	5	12	0.38
		Average Ratio:	**0.42**

Table 2: Ratios of dry to total deposition from available monitored deposition data at the Cedar Creek site for 1989-2003. *Source: CASTNET/NADP-NTN data for Cedar Creek.*

Year	Dry Dep CASTNET (S kg/ha/yr)	Total Dep CASTNET/NADP (S kg/ha/yr)	Ratio
1989	6	18	0.33
1990	5	17	0.26
1991	4	14	0.28
1992	4	14	0.25
1993	4	14	0.29
1994	4	14	0.25
1995	3	9	0.27
1997	3	10	0.31
1998	3	11	0.24
1999	3	9	0.31
2001	3	9	0.27
2002	2	9	0.23
2003	3	11	0.25
		Average Ratio:	**0.27**

For comparison, scaling factors based on the ratios of dry to total deposition from the 2002 base year CMAQ outputs were calculated. CMAQ deposition outputs are available as 12-km resolution raster files for wet and dry deposition of sulfur (kg/ha/yr). Because the CMAQ

modeling results are at such a coarse grid resolution, it is not appropriate to use the absolute values of the grid cells; however, they are useful for determining relative ratios such as this. This analysis indicated that the ratios of dry to total simulated deposition for the CMAQ grid cells in Tucker County, WV (where the Parsons NADP/CASTNET sites are located) and Gilmer County, WV (where the Cedar Creek sites are located) were 36% and 34%, respectively.

Based on these exercises, it was determined that 30%, 35% and 40% represent an appropriate range of dry to total deposition scaling factors. The ranges of current total sulfur deposition estimates for the LWPA using these scaling factors are shown in Table 3:

Table 3: Calculated range of total sulfur deposition (kg/ha/yr) in the Lower Williams Project Area. Note that the Grimm and Lynch (1997) wet deposition data in Figure 1 reflect sulfate values, whereas values here are converted to sulfur.

Year	Range of Total S Deposition in LWPA: 40% Scaling Factor		Range of Total S Deposition in LWPA: 35% Scaling Factor		Range of Total S Deposition in LWPA: 30% Scaling Factor	
	High	Low	High	Low	High	Low
2002	12.40	9.61	11.96	9.27	11.52	8.92

Future Year Deposition Estimates

Deposition estimates from CMAQ model runs conducted by the VISTAS RPO using the 2002 and 2018 emission inventories were used to estimate near-term deposition decreases. The emission inventory for the 2002 base year modeling run is considered representative of a typical operating year for all emission sources within the modeling domain. To calculate this representative inventory, an average of emissions from a four year period for each source that was considered representative of a typical operating year was used. The emission inventory for the 2018 out year modeling run includes anticipated emission changes that are expected to occur within the first Regional Haze planning period as a result of implementation of the Clean Air Interstate Rule (CAIR), application of Best Available Retrofit Technology (BART) and other regulatory initiatives. The emissions inventories also include estimates of current emissions and future emissions from area and mobile sources. Further information on the VISTAS emission inventories and the associated CMAQ modeling runs can be found on the VISTAS website (http://vistas-sesarm.org/). CMAQ modeling outputs for the eastern U.S. for the 2002 and 2018 modeling years are shown in Figures 2 & 3.

Figure 2: Modeled sulfur deposition from CMAQ using the base G 2002 VISTAS emissions inventory.
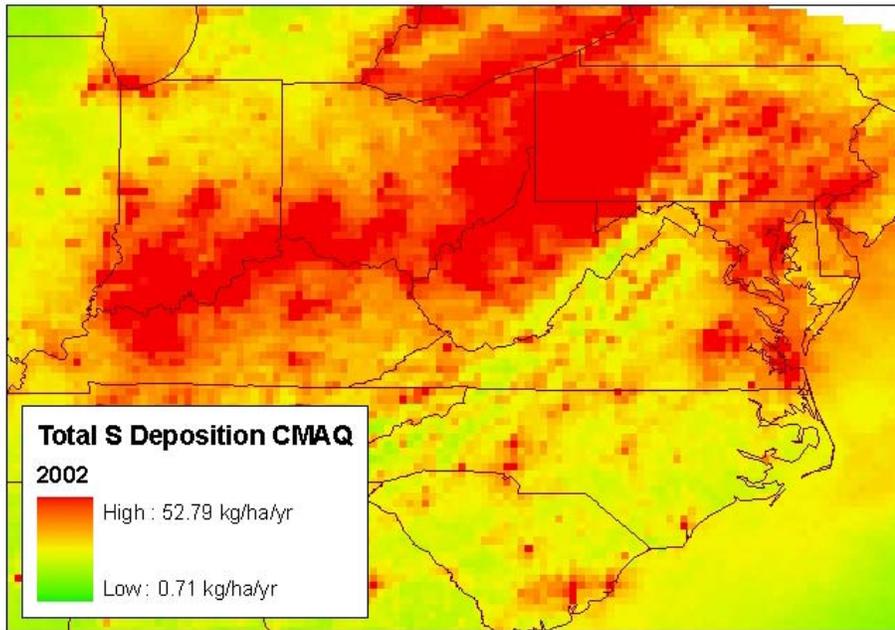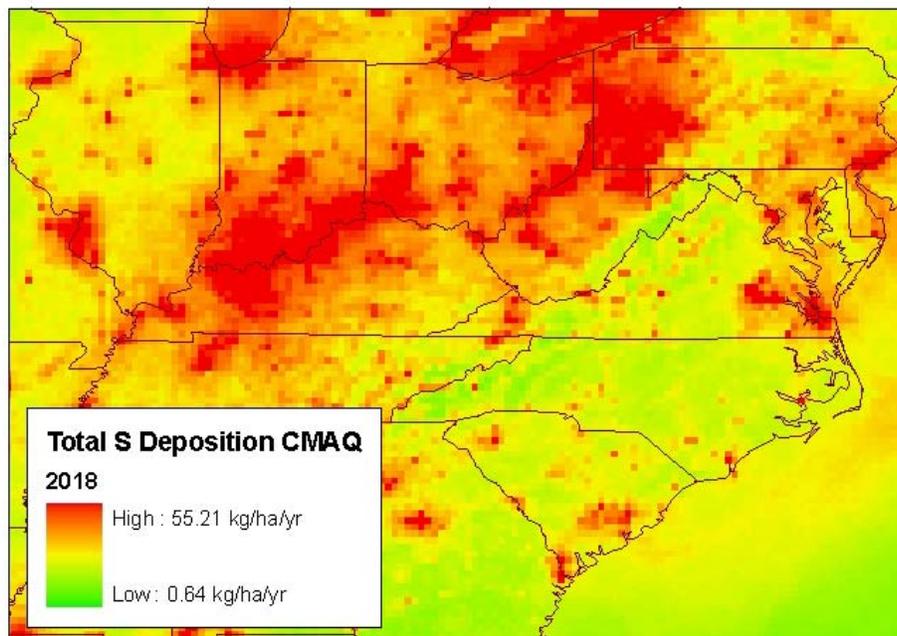

Figure 3: Modeled sulfur deposition from CMAQ using the base G 2018 VISTAS emissions inventory.

Again, because the absolute values of deposition estimates from the CMAQ model are not accurate, they were only used to determine the predicted percent change in deposition between the 2002 base year and the 2018 out year. The CMAQ modeling results projected a 48%

decrease in total deposition by the year 2018 in the LWPA. This 48% decrease was applied to the range of total deposition estimates in the LWPA derived previously from the Grimm and Lynch (1997) wet deposition data to arrive at the final future year deposition estimates (Table 4).

Table 4: Range of predicted total deposition in the LWPA for 2018.

Year	Range of Total S Deposition in LWPA: 40% Scaling Factor		Range of Total S Deposition in LWPA: 35% Scaling Factor		Range of Total S Deposition in LWPA: 30% Scaling Factor	
	High	Low	High	Low	High	Low
2002	12.40	9.61	11.96	9.27	11.52	8.92
2018	6.45	5.00	6.22	4.82	5.99	4.64
% Decrease	48%	48%	48%	48%	48%	48%

While these predicted decreases mean deposition of sulfur would be cut almost in half, as mentioned previously, this reduction may not be enough to restore the most sensitive ecosystem as identified in the 2005 NAPAP report.

Simulated Ecosystem Response – Dynamic Modeling
The Model of Acidification of Groundwater in Catchments (MAGIC) was run for 33 streams on the MNF. The MAGIC model can be used to predict stream water response to cumulative acidic deposition including the time to degradation or time to recovery for specified ANC endpoints for individual streams or catchments. It has been used extensively throughout North America and Europe and has been tested against the results of ecosystem manipulation experiments (Sullivan et al. 1992, 1996; Sullivan and Cosby 1995; Cosby et al. 1995, 1996). Stream water and soils data are used as inputs to calibrate the model for specific streams and catchments. Calibration procedures for the MNF study followed the protocols developed for the Southern Appalachian Mountains Initiative project (Sullivan and Cosby, Report for the MNF, 2004).

MAGIC was used to predict the sustained sulfur deposition loadings that would be needed to achieve one of four identified acid neutralizing capacity (ANC) endpoints within specified timeframes. The three time periods used in the MNF study within which the goal ANC endpoint should be achieved were 2020, 2040 and 2100. (This study assumed that total current deposition of sulfur is 18 kg/ha/yr.) The ANC endpoints used in the MNF study were 0, 20, 50 and 100 ueq L^{-1}. The first two ANC endpoint values are thought to correspond to chronic and episodic damage to brook trout populations (Bulger et al. 2000). Streams with ANC values between 20 and 50 ueq L^{-1} may be classified as sensitive to acidic deposition for brook trout, while streams with ANC values greater than 50 ueq L^{-1} are considered not sensitive. Other acid intolerant species may experience negative effects at higher ANC levels than those identified for brook trout.

Two streams for which MAGIC modeling results are available are located within the LWPA: Johnson Run and White Oak Fork (Figure 4). Table 5 displays the modeling results for these two sites.

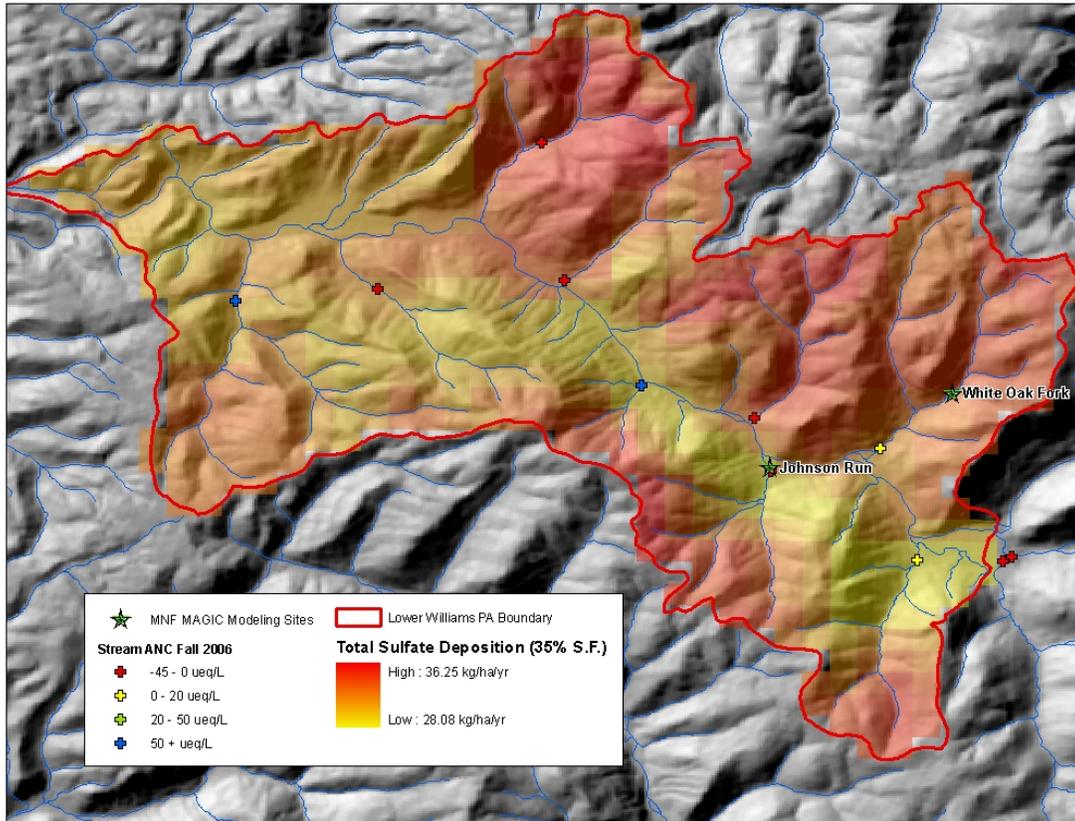**Figure 4: Locations of sites in the LWPA with MAGIC modeling results.**

Table 5: Estimated deposition (kg/ha/yr) of sulfur to reach a variety of ANC (ueq/L) endpoints in a variety of future years for modeled streams in the LWPA. All simulations were based on straight-line ramp changes in deposition from 2000 to 2010, followed by constant deposition thereafter. Blank entries indicate that ecological endpoint could not be achieved (no recovery) even if S deposition was reduced to zero.

Site	Modeled Calculated ANC (ueq/L)			Critical Load of S deposition to achieve ANC value											
				Endpoint ANC = 0			Endpoint ANC =20			Endpoint ANC =50			Endpoint ANC =100		
	pre-1900	*1975*	*1995*	*2020*	*2040*	*2100*	*2020*	*2040*	*2100*	*2020*	*2040*	*2100*	*2020*	*2040*	*2100*
Johnson Run	35	-5	-17												
White Oak Fork	41	17	6		2.4	5.8									

For Johnson Run, MAGIC back-calculated that pre-industrial ANC values were about 35 ueq L^{-1}, and modeled 1995 ANC values were below 0. In this situation, achievement of any of the ANC endpoints would represent an improvement in stream water chemistry. However, predictions show that recovery in Johnson Run will not occur for any ANC endpoint, even if deposition of sulfur decreases to 0 kg/ha/yr and a recovery time of up to 100 years is allowed (Table 5).

For White Oak Fork, MAGIC back-calculated that pre-industrial ANC values were about 41 ueq L^{-1}, and modeled 1995 ANC values were at 6 ueq L^{-1}. In this situation, reaching the ANC endpoints of 20, 50 or 100 would represent improvements in stream chemistry, while reaching the ANC endpoint of 0 would represent a degradation of stream water chemistry. The MAGIC model predictions in White Oak Fork show no improvements in ANC, even if sulfur deposition decreases to 0 kg/ha/yr with a recovery time through 2100. Additionally, even if deposition of

sulfur decreases to 2.4 kg/ha/yr, stream ANC is predicted to decrease to 0 ueq L^{-1} by 2040. The threshold of sulfur deposition is somewhat higher, 5.8 kg/ha/y, for the 2100 timeframe. This higher level of sustained deposition may reflect a greater degree of predicted base cation replacement in the system in conjunction with the lower S deposition rate by the year 2100.

Air Quality Evaluation Conclusions
No recovery in stream ANC levels is predicted to occur for the modeled streams within the LWPA, even if deposition of sulfur were to decrease to 0 kg/ha/yr. Based on the soils data and additional stream chemistry monitoring, if MAGIC modeling were conducted for other sites within the LWPA the results would be expected to be similar. Additionally, projected decreases in deposition that are expected to occur from currently implemented or on-the-books air quality regulations may not be enough to maintain an ANC above 0 ueqL^{-1} in White Oak Fork or Johnson Run, nor will they be enough to achieve improvements in stream ANC for the project area.

Acid Deposition

Resource Impacts or Issues Addressed

This section discloses the soil resource issues and impacts identified during interdisciplinary meetings and public scoping. The Forest Service identified soil resource issues associated with proposed actions:

Base Cation Depletion Issue
Background: Deposition of acidic air pollutants can result in base cation leaching from soils. The base cations of concern are primarily calcium and magnesium. Base cation leaching reduces soil reserves of these nutrients that are essential for plant growth and also can lead to increased stream acidity.   The soils occurring in the project area are rated as being sensitive to acidification because they are already having low base cations stores and high acidity. Trees take up calcium, incorporating it as a primary component in woody tissue and to a lesser extent in foliage. Harvesting trees removes nutrients, particularly calcium, from the site. The majority of nutrients would stay on site if limbs, leaves, and roots were left behind during harvesting. Soil erosion also can result in base cations losses from the site.
Issue: Harvesting trees may remove more base cations from the site than can be replenished through natural weathering processes, based on current and historic amounts of acidic deposition and soil types that occur in the area. Tree harvesting could exacerbate depletion of soil base cations, possibly resulting in further soil and stream water acidification.
The following units of measure are used in this EIS to evaluate this issue:

- Acres of harvesting by harvest method, prescription, and risk levels. Risk levels are based on soil chemical measures taken within the sub-watersheds and areas of harvest.

- Acres of disturbed soils.

Scope of the Analysis

The spatial boundary used to evaluate **direct** consequences is the activity areas where actions are proposed within the project area. Activity areas are those areas in which harvesting, herbicide treatment, and wildlife opening creation are proposed. This spatial boundary was chosen

because it can be used to determine threshold effects to soil quality from proposed actions associated with this project. **Indirect** consequences also are bounded within the project area because effects are not expected to move outside of the sub-watersheds within the project area. Refer to the Alternative Maps (Chapter 2) for the locations of the proposed activities.

The spatial boundary used to address **cumulative** impacts is the entire area. This allows the assessment of past and future effects and the determination of threshold impacts to soil quality as defined the Region 9 Soil Quality Standards FSH 2518, when added to the proposed actions. There are two frames for effects for this analysis, short term and long term. Direct, indirect, and cumulative effects can occur within short term and long term time frames. Short term effects to soils are considered to occur over a period of a decade. If recovery of the soil properties does not occur within this duration, effects then are considered to be more long term in nature. Long term effects to soils would last for more than 100 years. Soil formation, and thus, soil replacement take a long time (200-400 years) and depends on local climate and ecological conditions.

Methodology

The Proposed Action and Alternatives have the potential to affect soil resources as a result of commercial timber sale activities, road construction and reconstruction, and log landing construction and use. The effects of these activities may include soil disturbance, soil compaction, soil rutting, erosion, slumping and mass wasting, accelerated decomposition of organic mater, changes in nutrient cycling due to biomass removal and mixing of the soil surface horizons, and changes in soil temperature and moisture. The effects of these activities on soil resources in the activity area can be described in terms of short and long term effects on the **productivity or quality** of the soils. **Short term effects** are those effects expected to last less than a decade. Effects to the soil from tree felling and being skidded out of the stand on the soil surface may be an example. The soil surface is slightly mixed and disturbed. The time for soil properties to recover is short. For soils rarely, large scale disturbances are considered to short term in nature. It is only when the changes that occur to soil properties happen within the decade and the effects of those changes are no longer noticeable after a decade. In contrast, **long term effects** are associated with activities that displace soil permanently and change the physical, chemical, and biological properties of the soil. Many years are needed for the soil to recover its original productivity when the surface layers are removed, deeply compacted, or altered in some manner that changes the chemical composition such as the effects with intense fire in these ecosystems. Additions to the soil profile from fill would also have long term effects. An example of an addition to the soil may be adding fill to the top of the soil profile from road building. The long term effects from the acid deposition are in part due to the leaching of the base cation supply and the combination of base poor geologies in the project area. Soil formation typically occurs at a rate of one inch per 200-400 years, and depends on many local environmental factors.

Important factors considered in evaluating effects to soil resources from this project are: the extent of the activity area and the current soil chemistry data of different soils within the project area. Effects to the soils from this project are considered not significant when 85 percent of the activity area retains its potential long term **soil productivity** (Forest Service Handbook, 2509.18.2.2, Soil Quality Standards).

Affected Environment

Acid Deposition/Air Quality

See the "Affected Environment report in Appendix B for the acid deposition and air quality discussion.

An Overview of Soil Chemistry Relationships and Forest Productivity:

Forest productivity and sustainability have been issues of concern during recent years. Forest health decline and decreasing species diversity have been observed across North America and Europe (Binkley et al. 1998). Forest productivity throughout eastern United States and Canada has been declining for the past several decades (Bailey et al. 2004). Several factors influence the productivity and sustainability of forests, including disease, insect infestations, soil moisture, nutrient status, and acidic deposition. These factors rarely act independently -- more often they are interrelated (Binkley et al. 1998; Duchesne et al. 2003). For example, nutrient availability for forest trees can be affected deleteriously in areas subject to chronic, high levels of acidic deposition, which in turn can make those same trees susceptible to diseases or insect damage. Federer et al. (1989) stated "continual depletion of the total amount of any nutrient must sooner or later decrease its availability and, consequently, forest productivity." Thus, soil chemistry can play a key role in overall forest health, both directly and indirectly.

Some soil chemical factors that are believed to affect forest health and sustainability relative to acidic deposition are base cations (calcium, magnesium, potassium, sodium), effective cation exchange capacity, nutrient availability, acidity, nitrogen and sulfate saturation, and toxic metals, including aluminum and manganese (Adams et al. 2000). Base cations are important to sustaining forest health because they are macronutrients; calcium is particularly important because it is a primary component of bole wood. Base cations also neutralize soil acidity, thereby making other nutrients more available to forest vegetation. The main inputs of calcium to soils are by weathering, litter fall, and atmospheric deposition (Huntington 2000). However, the rate at which calcium is replaced by weathering tends to be very slow compared to rates of deposition, uptake, and leaching (USGS 1999). Schnably (2003) found that the potential replenishment of soil calcium in the Appalachians is low due to the highly weathered status of these soils. Older soils that form from base-poor geology are most susceptible to calcium depletion, whereas soils derived from limestone and dolomitic bedrock are the least susceptible to calcium depletion (Huntington et al. 2000).

Specific criteria need to be established for the assessment of forest ecosystem impacts on localized scales. Holmberg et al. (2001) stated, "In general, it would be easier to use a criterion concerning the behavior of the system as a whole, rather than one isolated feature, such as forest health. The fact that the link between forest health and changes in soil variables is ambiguous supports the use of a simpler criterion, relating to a higher level in the system hierarchy."

Several soil chemical factors, including Ca:Al molar ratio and base saturation, have been related to soil nutrient condition, with fewer of these factors related to forest health. Cronan and Grigal, (1995) noted that base saturation of the effective cation exchange capacity (BSECEC) ≤15% typically is associated with some level of forest decline. However, while relationships have been found, threshold values for each across various situations (i.e., climate, topographic, deposition, soil conditions, bedrock/parent material, physiography, etc.) have not been identified. Consequently, threshold values or at least levels of concern need to be defined, at least regionally, to model and predict forest productivity (Federer et al. 1989).

Soil Acidification:
Sulfuric and nitric acid enter forest soils via both wet and dry deposition of atmospheric pollutants (as well as natural sources such as volcanic emissions). In the soil, hydrogen ions (H^+) dissociate from the sulfate and nitrate ions. The dissociated H^+ provides acidity to the soil, which results in pH decreases (Sparks 2003). The addition of H^+ to soil by acid deposition results in further soil acidification by displacing base cations, particularly calcium and magnesium, from soil exchange sites (Sparks 2003), as illustrated below using calcium in the example:

$$2H^+ + SO_4^{2-} + Ca^{2+} \text{ (on exchange sites)} \rightarrow Ca^{2+} + SO_4^{2-} + 2H^+ \text{ (on exchange sites)}$$
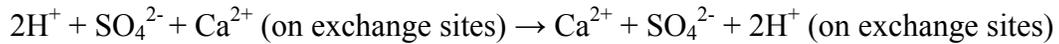
Upon becoming displaced from soil exchange sites, base cations pair with sulfate or nitrate anions to maintain the electroneutrality of the soil solution. These ion pairs can be leached through and from the soil by subsurface water moving laterally or vertically. Often the result is increased leaching losses to streams so that base cations are permanently lost from watershed soils. As base cations become depleted, additional hydrogen ion inputs displace acidic cations from the soil, principally aluminum (Al), but also other metals such as manganese (Mn) and iron (Fe) (Bache 1986).

Soil acidification reflects an increase of acid cations accompanied by a decrease in base cations (Yanai 2005). While soil weathering, soil biotic processes, and vegetative uptake are naturally acidifying processes (Gbondo-Tugbawa and Driscoll 2003) and acid deposition explains only about 38% of acidic input to ecosystems (Markewitz et al. 1998), there is evidence that acidic deposition has accelerated acidification of some soils. For example, a study of soil acidification in the upper 60 cm of soil in the Calhoun Experimental Forest in South Carolina has shown an accelerated rate of acidification caused by atmospheric deposition from 1962 to 1990 (Markewitz et al. 1998). In England, Blake et al. (1999) determined from a century-long study that acidic deposition was the main cause of soil acidification and acid deposition greatly accelerated soil acidification in the Geescroft Wilderness. Calcium is believed to have leached at double the natural rate in forests affected by acid deposition (Joslin et al. 1992). If leaching continues at current rates in the Panola Mountain watershed in Georgia, it is thought that in 150 years there will only be enough calcium in the soil for one hardwood rotation to reach marketable size (USGS 1999). Using a model simulation, Gbondo-Tugbawa and Driscoll (2003) found that there has been 20% depletion of soil calcium during the past 40 years in the Hubbard Brook Experimental Forest in New Hampshire.

Acidification of soils increases cation leaching, decreases soil pH and base saturation, and negatively affects many biological processes (Adams and Kochenderfer 1998). Adams and Kochenderfer (1998) found that the nitrogen content in trees increased from the artificial acidification of forest soils. In another study, Adams (1999) found that calcium losses were particularly large when a forest soil was artificially acidified compared to a non-acidified soil. A nine-year acidification study at Bear Brook watershed in Maine found accelerated losses of base cations from the soil to streams due to fertilizer additions of nitrogen and sulfur (Fernandez et al. 2003). Lawrence et al. (1999) also showed that calcium concentrations in leachate increased as experimental additions of acid concentrations increased.

The loss of base cations due to acidic deposition also is supported by other studies (Bailey et al. 2005). In an experiment using archived samples from 1967 and resampling in 1997, 1998, and 1999, Bailey et al. (2005) found that forest soils in the Allegheny National Forest had decreases in pH and exchangeable calcium and magnesium and increases in exchangeable aluminum, though these trends were not observed over the three-year sampling period. The majority of the change in calcium and magnesium could not be accounted for by forest growth, and they concluded that acid deposition was the driving force behind the cation leaching in the soil.

Another long term forest soils study showed similar results. Drohan and Sharpe (1997) resampled soils in Pennsylvania that had been initially sampled 14 to 36 years prior. They found that the upper soil horizons (O and A) showed decreases in pH, exchangeable calcium, and exchangeable magnesium with increased exchangeable aluminum in the A horizons. The main causes for the increased acidification and loss of base cations from these soils were forest uptake and acidic deposition (Drohan and Sharpe 1997).

Base cations are replenished in forest soils to some degree by mineralization of litter fall, atmospheric deposition, and weathering (Jenkins 2002; Johnson and Todd 1990). Slope position can play an important role in determining base cation levels. Lower slope positions accumulate more litter fall due to wind and gravity than higher slope positions (Johnson and Todd 1990); therefore, lower slope positions can have higher base cation concentrations. (See discussion regarding purpose and effects of Riparian Buffers.)

Ca:Al Molar Ratio:
The Ca:Al molar ratio is an indicator of the risk for forest decline due to aluminum antagonism and toxicity (Cronan and Grigal 1995). Natural soil acidification, intensive tree harvesting, and acid deposition all deplete base cations, and thus, potentially increase soil solution aluminum. Impaired uptake of already depleted calcium and magnesium supplies, growth reductions, and increased root mortality and turnover all are problems caused by high aluminum concentrations in soil (Cronan and Grigal 1995).

Soils with low Ca: Al molar ratios are more likely to have forest decline due to aluminum antagonism and toxicity. Cronan and Grigal (1995) estimated that a Ca:Al molar ratio of 1.0 results in a 50% risk of adverse impacts on forest; a Ca:Al molar ratio of 0.5 to 0.6 creates a 75% risk of adverse impacts on forest; while a Ca:Al molar ratio of 0.2 gives a 95% or greater risk of adverse impacts on forest (Cronan and Grigal 1995). The composite relationship Cronan and Grigal found in their review of over 300 references "is largely based on seedling responses under controlled conditions; it includes a mixture of more and less sensitive species studied under varying treatment conditions;. . . and it assumes that one can extrapolate from results with seedlings to mature trees growing under field conditions." (p. 219, Cronan and Grigal 1995.) "For perspective, it can be noted that half of the 14 North American and northern European watersheds including in the ALBIOS interregional study of Al bio-geochemistry. . . exhibited soil solution Ca/Al molar concentration ratios below 1.0 in the B horizon. . . Symptoms of Norway spruce decline were evident at three of those sites." (p. 218, ibid)

Jenkins (2002) found that soils in the Otter Creek watershed on the Monongahela National Forest in West Virginia commonly have a Ca:Al molar ratio <0.2, along with a base saturation of the effective cation exchange capacity (BSECEC) <15%. He interpreted these findings to mean that

the associated forests are at 100% risk for decline. Similar soils are located in the Lower Williams watershed.

Lyon and Sharpe (1999) found that the Ca:Al molar ratios in forest soils of Pennsylvania had the highest risk in the B horizons: the B horizons were determined to be the upper rooting zone of most tree species in the study (Lyon and Sharpe 1999). The Ca:Al molar ratios of the organic horizons were well above the threshold levels and not at risk. This is expected in that both momomeric and polymeric aluminum is complexed with organic compounds, and calcium is leached slowly from organic horizons (Lyon and Sharpe 1999). After determining the Ca:Al molar ratios for several sites in Pennsylvania, Lyon and Sharpe (1999) compared them to the status of sugar maple (*Acer saccharum* Marsh.)[*] growing at those sites. For declining stands, the median Ca:Al molar ratios were 13.2, 0.66, and 0.31, respectively, for the O horizon, A horizon, and B horizon. For non-declining stands, the median Ca:Al molar ratios were 17.6, 1.93, 10.8, respectively, for the O horizon, A horizon, and B horizon. The A and B horizon values were significantly lower in the declining stands.

Soil Sampling in the Lower Williams River:
The 2006 MNF Forest Plan provides direction with regard to soil assessments for areas determine to be sensitive to the effects of acid deposition. Forest Plan Standard SW08 – Management activities that have the potential to contribute to the soil nutrient depletion shall be evaluated for the potential effect of depletion in relation to on-site acid deposition conditions. Map X displays the Acid Deposition Soil Nutrient Sensitivity of the Lower William River project area. The majority of the watershed is rated as high risk. The Forest Plan EIS, Soil Resource section discusses how this map was made and the appropriate use of the map (pg 3-33 – 3-35, 2006.) The assessment is directly linked to geology. The geology of the area is discussed in detail in the Soil Productivity report, and Map 2 of that report displays the surface geology.

In 2006, a soil sampling project was initiated in the Lower Williams River watershed. This project was as part of a broader project conducted by West Virginia University (WVU) and the National Geospatial Database Center, USDA. The original purpose of this project was to validate predictive models used for remote soil survey techniques. In the summer of 2006, WVU staff sampled approximately 140 randomly located soil pits in and around the Lower Williams project area. Thirty of those soil pits fell within the defined project area (Map XX for location of Soil pits). The pits were located on multiple soil series, landscape positions, aspect, and geologies.

The Forest used these 30 soil pits to examine the current soil chemical and physical properties of the soils in the Lower Williams watershed and the potential effects of and mitigations for the proposed management activities. Results and interpretations pertaining to this EIS are discussed below. Further detail and raw data pertaining to the physical characteristics of the soil and the distribution of soil series can be found in Roecker (2007).

Chemistry Results from Soil Sampling Within the Project Area:
Thirty full characterization pits were excavated to 150 cm (80 in) or the most limiting soil layer such as bedrock, and a complete soil description was recorded using the Field Book for Describing and Sampling Soils, Version 2.0, September 2002, National Soil Survey Center, USDA Natural Resource Conservation Service, Lincoln, NB (ftp://ftp-fc.sc.egov.usda.gov/NSSC/Field_Book/FieldBookVer2.pdf). Soil pit descriptions are provided in project file.

The raw soil chemistry data, which include the general soil chemistry variables, are displayed in Table 1. Soils from two geologies were sampled in this data set – Mauch Chunk and Pottsville. Three parent materials (or however many you used since you called some residual/colluvial) also were examined (list them here). Colluvium soils form from material transported by water or gravity and typically accumulate in concave positions. Residuum soils form in place over the surface geology. Colluvium/residuum soils form on bedrock and in place but also have material deposited on the surface, usually from upslope. This often occurs in these mountainous areas because of steep slopes and complex terrain. Each of these parent materials was represented in

Table 1. Chemical properties of soils sampled in the Lower Williams River project area.

Field	Roecker ID	Horizon	Penn State Data Ca:Al Ratio Molar	Geology	Landform	Parent Material	Location	soil pH	% Calculated Base Saturation	% CALC. RISK	% LOI	% TN	% TC	Ca	K	Mg	Na	P	Al	Fe	Mn	Zn	meq/100g acidity	meq/100g ECEC	Calculated Base Saturation
																	Mg/Kg								
1	LW132	A	0.60	Pottsville			In project	4.4	36.7	75.0	4.5	0.14	2.31	46	40	8.9	12	1.3	209	1.7	12	2.5	2.5	2.9	36.7
2	LW132	Bw	0.52					4.5	26.1	75.0	4.0	0.09	1.66	24	28	5.0	4.0	1.1	146	1.7	5.6	0.6	2.1	2.3	26.1
3	LW132	C	0.49					4.7	20.6	75.0	2.0	0.03	0.25	22	18	4.1	3.1	< 1.0	144	1.4	10	0.5	2.1	2.3	20.6
4	LW132	Cr	0.26					4.7	19.0	>75	1.9	0.02	0.22	14	22	3.2	2.9	< 1.0	154	1.2	3.6	< 0.5	2.1	2.3	19.0
5	LW107	A	0.19	Alluvial Deposits	Toeslope	Alluvium	Just outside of project area	4.0	7.7	100.0	2.9	0.06	1.26	12	11	4.3	5.2	1.3	294	7.7	0.6	0.8	4.0	4.1	7.7
6	LW107	Bg1	0.09					4.5	13.4	100.0	4.5	0.08	1.21	31	54	7.7	9.1	2.1	558	13	2.0	1.3	7.2	7.6	13.4
7	LW107	Bg2	0.40					4.5	23.8	>75	3.1	0.06	1.03	40	40	27	5.1	1.1	319	5.5	6.2	9.2	4.2	4.7	23.8
8	LW110	A	3.92	Mauch Chunk	Backslope	Residuum	In project	4.3	64.7	0.0	9.5	0.28	3.06	266	131	75	11	3.8	415	1.8	97	2.7	5.1	7.5	64.7
9	LW110	Bt1	2.65					4.8	40.5	<50	4.9	0.07	0.69	113	37	71	8.1	1.0	299	1.7	8.9	0.8	4.4	5.7	40.5
10	LW110	Bt2	4.93					4.9	58.7	0.0	5.0	0.06	0.60	144	43	96	3.6	1.5	222	1.4	10	0.8	3.2	4.9	58.7
11	LW110	C	5.03					4.9	57.4	0.0	4.7	0.05	0.56	149	36	107	5.0	1.5	211	1.0	7.4	0.7	3.4	5.2	57.4
12	LW110	Cr	8.09					5.0	77.0	0.0	3.9	0.03	0.35	147	38	106	2.8	1.2	141	2.5	8.3	1.1	2.1	3.8	77.0
13	LW105	A	3.87	Mauch Chunk	Backslope	Colluvium	In project	4.2	42.6	0.0	9.1	0.30	3.53	266	63	43	8.6	3.7	533	2.7	23	5.1	7.0	8.9	42.6
14	LW105	Bt1	3.11					4.6	22.6	0.0	6.5	0.15	1.62	93	29	15	3.6	2.2	392	2.2	6.5	1.3	5.5	6.2	22.6
15	LW105	Bt2	1.09					4.6	18.0	<50	5.2	0.12	1.23	68	25	12	3.1	2.4	377	1.7	6.6	0.8	5.5	6.0	18.0
16	LW3	A	0.15	Pottsville	Shoulder	Residuum	In project	4.1	10.4	100.0	8.8	0.17	4.45	21	47	10	8.4	3.9	566	88	1.0	1.7	8.0	8.3	10.4
17	LW3	Bw	0.32					4.5	12.4	>75	4.2	0.07	1.33	11	22	3.5	5.1	2.3	271	4.7	< 0.5	< 0.5	3.2	3.4	12.4
18	LW3	C	0.27					4.5	11.7	>75	3.4	0.05	0.95	13	18	2.4	6.6	1.2	270	5.5	< 0.5	< 0.5	3.2	3.4	11.7
19	LW3	Cr	0.14					4.6	11.7	100.0	1.6	0.03	0.27	8.3	20	2.0	4.9	< 1.0	231	10	< 0.5	< 0.5	2.9	3.0	11.7
20	LW8	A	0.32	Pottsville	Summit	Residuum	In project	4.5	17.2	75.0	8.5	0.25	3.60	28	48	7.7	11	2.3	408	2.5	11	0.6	5.1	5.5	17.2
21	LW8	Bw1	0.30					4.7	15.3	>75	3.5	0.09	1.00	16	16	3.0	5.3	1.0	180	3.6	2.9	< 0.5	2.5	2.6	15.3
22	LW8	Bw2	0.25					4.7	15.9	>75	2.0	0.05	0.50	9.1	22	1.9	2.0	1.2	166	3.5	1.1	< 0.5	2.1	2.2	15.9
23	LW8	C	0.36					4.7	20.5	75.0	1.5	0.03	0.35	10	9	1.4	4.6	< 1.0	90	1.8	1.6	< 0.5	1.1	1.2	20.5
24	LW435	A	0.60	Pottsville	Backslope	Colluvium	In project	4.4	28.9	75.0	10.4	0.31	4.36	58	71	10	17	2.5	331	1.8	29	0.9	4.8	5.4	28.9
25	LW435	BA	0.23					4.5	21.3	>75	4.6	0.09	1.22	19	66	5.3	11	1.7	359	2.3	12	0.7	4.4	4.7	21.3
26	LW435	Bt	0.13					4.5	15.3	100.0	3.9	0.06	0.65	15	67	3.9	5.6	2.3	462	1.2	4.2	0.7	5.7	6.0	15.3
27	LW435	BC	0.17					4.5	11.7	100.0	4.1	0.05	0.48	15	48	3.9	6.5	1.9	474	3.9	3.8	< 0.5	6.1	6.3	11.7
28	LW113	A	0.28	Pottsville	Backslope	Residuum	In project	4.1	10.8	>75	10.7	0.24	5.44	25	63	18	7.9	4.3	779	49	3.3	2.0	10.1	10.5	10.8
29	LW113	Bw1	0.11					4.6	16.8	100.0	5.1	0.08	1.30	17	54	7.2	3.5	1.9	370	6.6	1.1	0.8	4.6	4.9	16.8
30	LW113	Bw2	0.17					4.6	11.8	100.0	3.5	0.05	0.56	10	36	3.3	3.2	1.3	304	4.8	0.7	0.6	4.2	4.4	11.8

Table 1. Chemical properties of soils sampled in the Lower Williams River project area.

Field	Roecker ID	Horizon	Penn State Data Ca:Al Ratio Molar	Geology	Landform	Parent Material	Location	soil pH	% Calculated Base Saturation	% CALC. RISK	% LOI	% TN	% TC	Mg/Kg Ca	K	Mg	Na	P	Al	Fe	Mn	Zn	meq/100g acidity	meq/100g ECEC	Calculated Base Saturation
31	LW114	A	1.38	Pottsville	Backslope	Residuum	In project	3.7	34.3	<50	13.9	0.46	9.89	191	66	21	8.3	4.6	498	33	24	2.9	7.0	8.4	34.3
32	LW114	Bw1	0.23					4.4	8.5	100.0	3.4	0.07	0.97	13	8	2.1	3.6	1.0	206	4.1	1.4	< 0.5	3.0	3.2	8.5
33	LW114	Bw2	0.18					4.6	10.9	100.0	2.6	0.04	0.60	15	21	2.1	2.9	1.4	236	4.7	0.8	< 0.5	3.6	3.8	10.9
34	LW431	A	1.18	Mauch Chunk	Backslope	Colluvium	In project	3.6	32.0	<50	9.5	0.31	4.70	112	78	26	12	3.9	444	38	12	1.3	6.1	7.1	32.0
35	LW431	Bw1	0.18					4.4	12.4	100.0	3.8	0.08	0.96	18	34	3.8	4.3	2.1	334	3.0	3.0	0.5	4.6	4.8	12.4
36	LW431	Bw2	0.17					4.5	14.9	100.0	3.5	0.04	0.36	21	18	5.0	4.1	1.0	237	6.3	4.3	0.6	3.0	3.3	14.9
37	LW431	Bt	0.24					4.6	16.9	>75	3.7	0.04	0.48	23	32	7.7	2.5	1.7	288	1.5	8.8	0.6	3.6	3.9	16.9
38	LW431	BC	0.44					4.6	16.9	>75	4.0	0.05	0.54	33	32	16	3.0	1.7	338	1.1	18	0.8	4.6	5.0	16.9
39	LW80	A	0.24	Pottsville	Shoulder	Colluvium/Residuum	In project	3.7	16.0	>75	9.2	0.31	3.67	50	78	15	5.9	4.7	663	12	38	2.3	8.7	9.3	16.0
40	LW80	BAt	0.22					4.2	7.5	>75	5.3	0.13	1.65	17	34	5.7	4.1	3.4	607	10	7.4	1.7	7.8	8.0	7.5
41	LW80	Bt	0.24					4.4	8.7	>75	7.2	0.15	2.03	18	38	5.3	3.9	2.9	529	7.4	3.3	1.0	7.2	7.5	8.7
42	LW80	Btx	0.21					4.6	10.5	100.0	3.5	0.04	0.36	12	23	2.6	3.5	1.6	308	10	2.4	0.8	3.8	4.0	10.5
43	LW85	A	8.62		Shoulder	Colluvium	Outside Project Area	4.6	57.7	0.0	8.0	0.22	3.02	302	35	27	5.6	2.3	333	2.1	13	0.6	4.6	6.4	57.7
44	LW85	Bt1	1.61					4.7	29.3	<50	4.3	0.06	0.59	119	26	13	4.1	1.7	358	1.1	7.5	< 0.5	4.8	5.5	29.3
45	LW85	Bt2	1.96					4.7	29.3	<50	4.4	0.05	0.46	131	38	17	2.1	2.1	397	1.3	4.7	0.6	5.5	6.4	29.3
46	LW85	Bt3	2.35					4.8	36.6	<50	4.4	0.05	0.34	153	49	33	2.0	1.4	384	5.0	4.2	< 0.5	5.3	6.5	36.6
47	LW85	Bt4	1.53					4.8	35.2	<50	3.8	0.03	0.24	108	27	24	3.8	1.2	296	2.2	8.4	< 0.5	3.8	4.6	35.2
48	LW10	A		Pottsville	Backslope	Colluvium	In project	4.5	17.8	75.0	9.8	0.20	4.08	29	52	8.8	12	2.3	458	7.0	2.5	0.9	5.3	5.7	17.8
49	LW10	BA	0.33					4.7	12.5	>75	5.5	0.10	1.51	29	35	6.5	5.1	2.1	488	8.4	1.1	0.7	5.7	6.0	12.5
50	LW10	Bt1	0.14					4.8	9.2	100.0	3.8	0.06	0.75	16	23	3.8	2.9	1.3	362	4.2	< 0.5	0.5	4.8	4.9	9.2
51	LW10	Bt2	0.08					4.7	5.9	100.0	1.9	0.03	0.32	8.2	6	1.3	2.0	< 1.0	224	2.8	< 0.5	0.6	2.9	2.9	5.9
52	LW10	Bt3	0.07					4.7	10.4	100.0	2.0	0.03	0.39	13	7	2.3	2.0	< 1.0	184	1.6	< 0.5	< 0.5	2.3	2.4	10.4
53	LW10	Bt4	0.14					4.5	11.6	100.0	3.2	0.04	0.21	14	45	3.4	2.0	1.8	419	2.9	< 0.5	< 0.5	5.3	5.5	11.6
54	LW10	Bt5	0.27					4.6	11.8	>75	2.4	0.03	0.25	12	25	3.0	2.8	1.3	276	7.4	< 0.5	< 0.5	3.4	3.6	11.8
55	LW86	A	1.57	Pottsville	Backslope	Colluvium/Residuum	In project	4.0	30.4	<50	8.7	0.32	2.82	147	92	21	6.6	4.2	532	2.5	138	2.6	7.6	8.8	30.4
56	LW86	Bt1	0.63					4.6	14.2	75.0	5.7	0.13	1.22	36	29	5.1	4.9	1.5	395	1.1	16	1.2	4.9	5.3	14.2
57	LW86	Bt2	1.03					4.7	19.0	50.0	4.8	0.09	0.83	49	37	6.5	2.0	1.5	304	2.4	11	2.5	4.6	5.0	19.0
58	LW86	C	0.49					4.7	17.9	75.0	4.7	0.09	0.88	45	21	6.0	10	3.9	284	2.3	7.2	4.1	4.2	4.6	17.9
59	LW86	2C	2.46					4.8	20.4	<50	5.7	0.08	0.96	73	34	8.8	7.7	< 1.0	363	1.1	3.5	2.1	5.5	6.1	20.4

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Field	Roecker ID	Horizon	Penn State Data Ca:Al Ratio Molar	Geology	Landform	Parent Material	Location	soil pH	% Calculated Base Saturation	% CALC. RISK	% LOI	% TN	% TC	Ca	K	Mg	Na	P	Al	Fe	Mn	Zn	meq/100g acidity	meq/100g ECEC	Calculated Base Saturation
60	LW11	A	8.08	Pottsville	Shoulder	Residuum	In project	4.0	84.8	0.0	5.4	0.12	2.27	78	39	11	3.2	6.0	24	3.6	9.2	2.2	1.0	1.5	84.8
61	LW11	C	0.74					4.2	269.0		0.9	0.02	0.22	8.9	5	1.3	2.1	1.1	15	1.3	< 0.5	< 0.5	< 0.2	0.1	269.0
62	LW434	A	0.16	Pottsville	Backslope	Colluvium/Residuum	In project	4.4	14.9	100.0	3.9	0.09	1.66	14	37	5.1	4.3	1.7	313	5.2	3.1	0.8	3.8	4.0	14.9
63	LW434	Bw1	0.20					4.6	12.2	100.0	3.3	0.05	0.62	10	29	4.2	4.7	4.8	295	2.4	1.3	4.4	3.8	4.0	12.2
64	LW434	Bw2	0.07					4.5	8.4	100.0	2.5	0.03	0.33	6.8	27	2.7	2.3	< 1.0	351	2.7	0.7	< 0.5	4.6	4.7	8.4
65	LW434	Bw3	0.17					4.7	10.1	100.0	2.5	0.03	0.32	12	34	7.9	4.1	1.1	327	1.0	0.6	< 0.5	5.5	5.7	10.1
66	LW434	2Bw4	0.28					4.8	11.3	>75	6.0	0.09	1.20	18	55	16	3.7	1.6	480	1.6	5.6	< 0.5	7.8	8.2	11.3
67	LW434	2C	0.12					4.5	11.9	100.0	6.2	0.11	1.47	25	57	10	5.7	2.3	587	1.2	6.7	0.8	7.8	8.2	11.9
68	LW199	A	12.27	Mauch Chunk	Backslope	Colluvium	In project	4.3	63.8	0.0	10.6	0.32	4.25	543	78	89	12	3.7	523	2.9	32	2.6	7.6	11.3	63.8
69	LW199	BAt	58.94					5.0	96.8	0.0	6.7	0.17	2.24	674	38	120	8.5	2.6	337	1.2	7.8	1.0	4.2	8.7	96.8
70	LW199	Bt1	9.47					4.8	44.5	0.0	5.3	0.11	1.66	250	24	58	11	1.8	345	2.1	5.6	0.5	5.9	7.7	44.5
71	LW199	Bt2	3.38					4.8	42.3	0.0	4.3	0.07	0.83	171	27	43	6.8	3.2	286	1.9	3.6	0.5	4.6	5.9	42.3
72	LW401	A	2.44	Mauch Chunk	Backslope	Residuum	In project	4.6	57.1	<50	7.5	0.23	3.45	198	41	26	6.7	2.2	209	1.1	24	1.0	3.4	4.8	57.1
73	LW401	BA	1.29					4.6	35.8	<50	4.8	0.11	1.65	85	41	15	6.1	1.8	274	1.6	13	< 0.5	3.4	4.1	35.8
74	LW401	Bt1	1.58					4.8	37.4	<50	2.9	0.03	0.28	114	46	28	3.4	1.5	318	1.2	6.3	0.8	4.2	5.1	37.4
75	LW401	Bt2	1.42					4.7	30.2	<50	2.9	0.03	0.26	111	44	30	3.9	1.5	368	2.1	7.5	< 0.5	5.3	6.3	30.2
76	LW401	Bw	1.13					4.7	29.4	<50	3.2	0.04	0.54	62	30	14	3.3	1.1	208	1.8	7.5	< 0.5	3.2	3.7	29.4
77	LW94	A	0.18	Pottsville	Backslope	Colluvium	Just outside of Project bndy	4.0	8.5	100.0	14.1	0.32	6.62	28	40	14	12	3.7	854	42	5.0	1.6	10.5	10.9	8.5
78	LW94	BA	0.49					4.6	13.1	>75	8.3	0.14	3.03	22	27	5.1	11	2.2	305	5.5	0.8	2.1	4.8	5.0	13.1
79	LW94	Bw1	0.19					4.7	8.2	100.0	4.7	0.06	1.18	6.7	10	1.2	4.3	1.2	205	1.9	0.8	< 0.5	2.7	2.7	8.2
80	LW94	Bw2	0.46					4.6	16.3	75.0	3.2	0.04	0.58	8.1	36	1.8	2.6	1.2	221	1.3	2.1	< 0.5	2.9	3.0	16.3
81	LW94	Bw3	0.20					4.7	10.2	100.0	3.4	0.05	0.74	6.3	12	1.0	5.2	< 1.0	178	2.8	1.3	< 0.5	2.3	2.4	10.2
82	LW94	BC	0.19					4.6	9.8	100.0	11.8	0.18	4.18	22	24	3.8	13	2.0	405	4.3	1.6	< 0.5	6.1	6.3	9.8
83	LW400	A	1.43	Pottsville	Shoulder	Residuum	In project	3.9	33.2	<50	14.2	0.48	7.40	153	78	25	5.2	4.3	453	4.3	190	1.9	6.7	7.8	33.2
84	LW400	BA	0.71					4.6	17.6	50.0	5.0	0.12	1.55	29	27	5.6	3.7	1.8	261	1.5	23	0.7	3.4	3.7	17.6
85	LW400	Bt	0.36					4.6	14.5	>75	2.9	0.07	0.65	34	48	6.2	11	2.1	508	2.3	11.3	< 0.5	6.5	6.9	14.5
86	LW400	Cr	0.34					4.5	13.1	>75	2.9	0.05	0.41	47	57	8.3	5.3	2.9	715	1.9	5.0	< 0.5	8.6	9.0	13.1
87	LW87	A	0.77	Pottsville	Backslope	Colluvium/Residuum	In project	3.9	20.4	50.0	7.5	0.21	4.75	45	50	23	6.5	3.2	403	20	22	2.5	5.5	6.1	20.4

Table 1. Chemical properties of soils sampled in the Lower Williams River project area.

Field	Roecker ID	Horizon	Penn State Data Ca:Al Ratio Molar	Geology	Landform	Parent Material	Location	soil pH	% Calculated Base Saturation	% CALC. RISK	% LOI	% TN	% TC	Ca	K	Mg	Na	P	Al	Fe	Mn	Zn	acidity meq/100g	ECEC meq/100g	Calculated Base Saturation
88	LW87	Bt1	1.33					4.8	20.7	<50	4.4	0.08	1.38	14	51	5.2	2.1	1.1	231	3.0	9.2	0.5	3.2	3.5	20.7
89	LW87	Bt2	0.22					4.6	19.3	>75	3.0	0.05	0.59	16	54	7.1	2.0	1.2	289	3.6	2.6	< 0.5	3.8	4.1	19.3
90	LW87	Bt3	0.22					4.7	18.2	>75	3.2	0.04	0.32	16	49	21	4.7	1.1	372	2.1	1.9	0.6	4.6	5.0	18.2
91	LW93	A	0.40	Pottsville	Backslope	Colluvium	Just outside of Project bndy	3.7	16.3	>75	6.6	0.18	2.73	44	63	15	3.9	1.8	499	28	4.5	1.3	7.2	7.7	16.3
92	LW93	Bt1	0.31					4.2	17.4	>75	7.8	0.19	2.71	24	58	9.1	12	1.9	439	5.9	6.3	1.0	5.5	5.9	17.4
93	LW93	Bt2	8.95					4.6	18.8		5.6	0.11	1.51	22	45	6.4	3.5	1.5	303	4.3	5.2	0.5	3.8	4.1	18.8
94	LW93	Bt3	0.34					4.7	23.1	75.0	4.6	0.06	0.66	39	49	30	4.9	1.1	367	18	4.0	0.7	4.8	5.3	23.1
95	LW89	A	0.43	Pottsville	Backslope	Colluvium	In project	3.7	18.5	75.0	9.6	0.32	5.01	55	57	16	6.1	2.5	417	26	11	1.3	6.7	7.2	18.5
96	LW89	B/A	0.96					4.7	17.0	50.0	4.0	0.09	1.52	15	19	3.5	4.6	< 1.0	173	4.0	0.8	< 0.5	2.3	2.5	17.0
97	LW89	Bt1	0.22					4.6	12.0	100.0	2.5	0.05	0.73	9.2	23	3.2	2.4	< 1.0	216	6.2	< 0.5	< 0.5	3.0	3.2	12.0
98	LW89	Bt2	0.10					4.6	12.4	100.0	2.3	0.04	0.39	10	35	3.9	2.1	< 1.0	298	8.0	1.2	< 0.5	4.0	4.2	12.4
99	LW89	C	0.08					4.7	13.3	100.0	2.4	0.03	0.30	13	30	3.7	9.0	3.0	306	4.6	0.8	2.6	4.0	4.2	13.3
100	LW90	Bt1	0.09	Pottsville	Backslope	Colluvium	In project	4.4	13.1	100.0	3.2	0.04	0.46	10	41	4.5	2.0	1.6	300	16	0.6	0.6	4.2	4.4	13.1
101	LW90	Bt2	0.13					4.5	16.9	95.0	3.2	0.04	0.47	12	40	7.5	5.5	< 1.0	247	8.3	1.3	0.9	3.6	3.9	16.9
102	LW90	Bt3	0.11					4.5	12.5	100.0	3.3	0.04	0.64	11	35	3.7	2.2	1.0	297	6.8	1.0	0.6	4.0	4.2	12.5
103	LW90	C	0.09					4.4	13.2	100.0	3.2	0.04	0.78	16	29	4.4	3.2	1.3	303	16	1.6	0.7	3.8	4.0	13.2
158	LW26	A	1.29	Pottsville	Backslope	Colluvium/Residuum	Just outside of Project bndy	3.5	36.9	<50	12.3	0.38	6.24	231	119	49	7.1	5.0	638	38	12	1.6	9.1	11.0	36.9
159	LW26	Bt1	0.20					4.1	6.7	100.0	6.0	0.12	1.88	31	38	8.4	3.0	3.4	928	18	3.1	1.0	11.6	11.9	6.7
160	LW26	Bt2	0.21					4.4	6.7	100.0	6.3	0.12	1.64	21	46	7.7	7.5	3.5	927	7.6	3.2	1.1	12.0	12.3	6.7
161	LW26	Bt3	0.10					4.6	7.6	100.0	5.1	0.08	0.86	20	52	6.9	5.5	3.5	828	3.3	4.1	1.1	10.8	11.1	7.6
162	LW26	Bt4	0.16					4.7	8.7	100.0	4.3	0.05	0.30	36	67	11	4.8	3.3	1015	1.7	13	1.6	13.1	13.6	8.7
163	LW26	Cr	0.30					4.7	13.3	>75	3.6	0.04	0.20	66	69	11	4.3	2.8	774	5.5	1.8	1.0	10.6	11.3	13.3
164	LW74	A	0.21	Pottsville	Backslope	Residuum	In project	4.1	9.8	100.0	11.2	0.25	5.49	33	51	13	7.5	3.3	755	27	2.1	2.8	10.3	10.7	9.8
165	LW74	Bt1	0.15					4.7	11.4	100.0	3.6	0.06	0.68	18	53	5.8	4.8	2.2	562	6.5	0.6	0.7	6.8	7.1	11.4
166	LW74	Bt2	0.23					4.7	13.4	>75	3.4	0.05	0.50	26	51	6.8	2.0	1.4	478	3.3	1.0	0.6	6.1	6.4	13.4
167	LW74	Bt3	0.47					4.7	10.6	>75	2.3	0.03	0.28	11	18	2.7	2.5	< 1.0	234	2.6	1.8	< 0.5	3.0	3.2	10.6
168	LW74	Btx	0.52					4.8	14.7	75.0	2.4	0.02	0.25	12	18	2.9	2.0	< 1.0	180	4.1	1.0	< 0.5	2.3	2.4	14.7
169	LW97	A	19.08	Mauch Chunk	Shoulder	Residuum		4.7	92.0	0.0	7.6	0.24	2.75	552	66	53	11	2.6	303	2.9	17	0.9	4.0	7.4	92.0
170	LW97	Bt	15.84					5.0	72.6	0.0	4.4	0.09	0.91	344	43	43	7.3	1.3	288	1.3	8.7	< 0.5	3.8	6.0	72.6
171	LW97	Cr	5.87					4.8	53.4	0.0	3.6	0.05	0.38	298	58	52	9.6	1.5	466	1.8	4.3	< 0.5	5.7	7.8	53.4
172	LW121	A	6.12	Mauch Chunk	Backslope	Colluvium	Outside project	4.1	73.1	0.0	9.6	0.32	3.58	388	108	56	9.1	2.5	224	4.8	109	4.4	4.9	7.7	73.1

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Table 1. Chemical properties of soils sampled in the Lower Williams River project area.

Field	Roecker ID	Horizon	Penn State Data Ca:Al Ratio Molar	Geology	Landform	Parent Material	Location	soil pH	% Calculated Base Saturation	% CALC. RISK	% LOI	% TN	% TC	Ca	K	Mg	Na	P	Al	Fe	Mn	Zn	acidity (meq/100g)	ECEC (meq/100g)	Calculated Base Saturation
173	LW121	AB	4.33					4.4	36.6	0.0	8.0	0.21	2.24	172	61	30	7.6	2.9	480	0.9	41	2.3	6.1	7.4	36.6
174	LW121	Bt1	15.15					4.9	70.5	0.0	4.7	0.10	0.99	310	30	64	3.7	1.4	217	1.3	9.2	0.6	3.6	5.8	70.5
175	LW121	Bt2	10.69					4.9	49.1	0.0	4.5	0.07	0.68	165	22	48	6.2	< 1.0	164	2.0	5.0	< 0.5	3.6	4.9	49.1
176	LW121	Bt3	18.57					5.0	86.9	0.0	4.4	0.07	0.67	365	41	80	7.1	1.3	219	0.5	11	< 0.5	3.0	5.7	86.9
177	LW151	A	1.00	Pottsville	Backslope	Residuum	Outside project	4.3	20.5	50.0	7.4	0.19	2.14	120	85	25	9.5	3.5	701	2.5	18	1.3	10.6	11.7	20.5
178	LW151	Bt1	0.29					4.6	13.8	>75	4.9	0.13	1.07	62	64	13	6.6	3.2	824	0.7	8.9	1.2	9.9	10.5	13.8
179	LW151	Bt2	0.32					4.7	24.6	>75	4.7	0.10	0.70	163	60	18	7.4	2.9	677	1.1	11	1.4	8.9	10.1	24.6
180	LW151	Bt3	0.28					4.6	14.2	>75	4.0	0.06	0.30	48	58	12	6.9	2.2	549	< 0.5	9.8	0.8	8.4	8.9	14.2
181	LW151	Cr	1.53					4.8	28.7	<50	3.8	0.05	0.19	143	91	42	6.9	2.3	700	0.8	4.0	0.7	8.6	9.9	28.7
182	LW174	A	1.78	Mauch Chunk	Backslope	Colluvium/Residuum	Outside project	3.9	29.3	<50	10.0	0.31	3.77	236	73	32	8.5	4.1	814	41	10	2.7	10.3	11.9	29.3
183	LW174	Bt1	0.95					4.5	14.3	50.0	6.9	0.15	1.87	63	36	8.3	3.6	2.4	533	2.5	2.2	0.7	7.2	7.7	14.3
184	LW174	Bt2	0.91					4.7	15.8	50.0	6.1	0.11	1.39	56	26	8.1	6.3	1.5	463	1.5	2.1	0.5	5.7	6.1	15.8
185	LW174	Bt3	0.86					4.8	19.3	50.0	3.6	0.04	0.35	52	27	6.5	2.6	< 1.0	285	0.6	2.9	< 0.5	4.2	4.6	19.3
186	LW174	Bt4	1.05					4.8	24.2	<50	3.7	0.04	0.27	79	40	11	4.6	1.4	392	< 0.5	4.6	< 0.5	4.9	5.5	24.2

Field - This is the lab sample id #

Roecker ID- This is the WVU soil pit ID#

Roecker project occurred across several watersheds within and around the Lower Williams Project Area.

the respective geology. Soil pits were also grouped into landforms: summit, backslope, shoulder, toeslope, and floodplain (alluvium) positions. Summits are ridge tops on the top of mountains and are usually less than 5 percent in slope. Backslope positions are located on the side of mountains. Shoulders are located above the backslope position but below the summit. Toeslopes are found at the base of the mountain just above the floodplain. The floodplain is where the stream runs through the mountains. Slopes in this landscape position are usually less than 8 percent.

Statistical analyses were run using SAS/STAT software (http://www.sas.com/technologies/analytics/statistics/stat/factsheet.pdf). Analyses were performed in two separate steps: 1) to examine whether there were statistically significant differences between the two geologies Mauch Chunk and Pottsville Formations (described in detail in the Soil Productivity Report) and among the 3 representative parent materials within the geologies, and 2) to examine whether there were statistically significant differences within horizons between the two geologies or among the parent materials within the geologies. Thus, the first set of analyses examined pooled all the horizon data together, while the second set of analyses focused on the soil horizons. For the horizon-specific analyses, all A horizons were group together, all B horizons (AB, BA, Bt, Bw, etc.) were grouped together, and all C horizons (C and BC) were grouped together by soil pit for analyses.   Field data included in the analysis came from soils sampled from a variety of landforms, but only pits from shoulder and backslope position were used in the statistical analysis because of the limited sample size in the other landform positions of summit, toeslope, and alluvium.   Because shoulder and backslope positions are very similar in location, they were considered a single landform for analyses and the data were then lumped together.

Tukey-Kramer tests were used to make the pair-wise comparisons of least square means. Least square means were used because they adjust for unequal sample sizes. All means presented in the tables in this section are least square means.

Soil Acidity
The parameters included in the soil acidity data set are pH, acidity, effective cation exchange capacity (ECEC), and base saturation of the effective cation exchange capacity (BSECEC). The effective cation exchange capacity (ECEC) was partially explained by soil pH (Sponaugle, 2005). As pH increased, in general ECEC decreased within each pit. However, the typical trend for many soils is an increase in ECEC as pH increases (Brady and Weil 2002). This increase was seen in the C horizons for several pits but only within the deepest portion of the pit closest to bedrock. The low range of pH values maintained an aluminum- controlled ECEC rather than base-cation controlled ECEC that occurs at a pH of ≥5.5 (Brady and Weil 2002). Johnson (2002) also found this negative relationship in soils in the northeastern United States.

In general, acidity was statistically less than acidity measured in the B horizon for colluvium over residuum soils in the Pottsville geology compared to colluvium in the Pottsville, and residuum and colluvium in the Mauch Chunk geology. This is did not support the hypothesis that colluvial soils in the Pottsville would be less acid than those

forming in residual material because colluvial soils receive inputs from material upslope. The only statistically significant difference
in pH was for the B horizon comparison between geologies. Pottsville B horizons had lower pH than B horizons from the Mauch Chunk. This was expected.

Soil pH in the Lower Williams River watershed generally increased with depth in the majority of the pits in the project area, though about 20 percent of the sampled pits had decreasing pH with depth. This pattern is explained by the incorporation of organic matter and deposition of acids to the surface. Organic matter inputs provide nutrients as well as organic acids to the soil (Brady and Weil 2002; Johnson 2002). The lower soil horizons apparently have retained nutrients. Typically, the pH of soils in the Northeast decreases with depth due to the low base status parent material of the region (Drohan and Sharpe 1997).

Base Cations
Base cations are calcium, magnesium, potassium, and sodium. Calcium (Ca) was the dominant base cation in these soils, with potassium (K) being the next most abundant. This analysis focuses primarily on Ca and Mg because they are the nutrients that are in very low supply in the Pottsville geology in comparison to other forest soils (Jenkins, 2002) and consequently are in short supply in the soil. Calcium and magnesium are also susceptible to depletion in the soil because of the continuing additions of strong anions (SO_x and NO_x) from the atmospheric deposition. Calcium and magnesium were statistically higher in soils forming from the Mauch Chunk geology than soils forming from the Pottsville geology. The red shale of the Mauch Chunk geologic profile is imbedded with calcite and forms soils with higher clay mineral content which allows for more Ca and Mg to be stored in soil on the exchange sites (NRCS, WV Soil Survey, NSSL data storage site 2006 and 2005 soil characterization projects.)   Calcium and magnesium both decreased with depth in the upper most horizons of the soil profiles. At lower depths, Mg concentrations level off while calcium slightly increased. In general, potassium and sodium decreased with depth throughout the entire profile and sodium slightly increased in the lower horizons following the same trend as calcium while potassium leveled off similar to magnesium.

Base saturation was statistically much lower for soils formed both by residuum and colluvium parent materials of Pottsville geology compared to soil formed in Mauch Chunk geology. Calcium and magnesium controlled these differences. The majority of units are located on soil series formed from the Pottsville.

There were no significant difference for potassium or sodium between geologies or within parent materials and horizons.

Acid Cations
The acid cations include aluminum (Al), iron (Fe), and manganese (Mn). No differences were found for manganese between the soils forming from the Pottsville geology and the soils forming in the Mauch Chunk. Aluminum values were not significantly different between geologies; however there were differences in the B horizon for soils formed in

colluvium/residuum in the Pottsville versus soils formed in colluvium in the Mauch Chunk. Aluminum was significantly higher in the B horizon for soils in the Pottsville geology. Iron and aluminum were present in significantly greater amounts in the A horizon than in the upper B horizon. Aluminum and iron decreased with depth throughout the soil profile; however, aluminum increased in the lower portion of the profile in some individual pits in the Pottsville geology. Aluminum and iron decreases were partially explained by the pH and acidity of the soils. As pH drops below 5.5, aluminum controls the acidity and ECEC of soil (Skyllberg 1999). Between pH 4.0 and 5.5, hydrolysis and dissolution of aluminum and iron hydroxyoxide minerals occurs (Skyllberg 1999). These processes release iron and aluminum oxides into the soil solution. Presumably, the low pH range of 3-5 in Lower Williams River watershed soils promoted these reactions, thereby releasing greater quantities of aluminum and iron. Jenkins (2002) and Sponaugle (2006) found similar results for soils in the same geology in other areas of West Virginia.

Summary of Data Analyses:
The general soil chemistry for the Lower Williams River watershed showed some trends that have implications with respect to soil acidification. Base saturation, calcium, and magnesium all followed trends that show soil formed from the Pottsville geology has significantly lower base cation nutrient levels compared to soils forming from the Mauch Chunk geology. The differences are seen most commonly in B horizons.   The majority of tree roots occur within 90 cm of the surface of the soil with feeder roots in the upper 60 cm (Oettinger 2005). The B horizons of the soils sampled in Lower Williams River watershed were above 60 cm in the zone of the feeder roots. B-horizon chemistry has been correlated most strongly with foliar chemistry in sugar maple (Bailey et al. 2004). Therefore, the B horizon data were used for making management recommendations.

Acid Risk Assessment:
The Ca:Al molar ratio of the soil solution can be used as an indicator of forest damage from aluminum stress. Based on analyses by Cronan and Grigal (1995), a Ca:Al molar ratio of 1.0 is associated with a 50% risk of adverse impacts to forest; a Ca:Al molar ratio of 0.5 to 0.6 is associated with a 75% risk of adverse impacts to forests; a Ca:Al molar ratio of 0.2 is associated with a 95% or greater risk of adverse impacts to forests. A ratio of 0.2 along with a BSECEC of less than 15% equates to a 100% risk of adverse forest impacts (Cronan and Grigal 1995). These threshold values were set using tree seedling growth and mortality. Thus, this risk is interpreted to be a risk for regeneration failures as the source for forest productivity decline. The values set by Cronan and Grigal (1995) were based on soil solution sampling. However, the calcium and aluminum data obtained from $SrCl_2$ extraction method (Joslin and Wolfe, 1989) were from soil samples. These data were used because no soil solution data were available and because this extraction method approximates values obtained in soil solution since it extracts "plant available" calcium and aluminum. The BSECEC used in the assessment came from the extractions performed by the University of Maine. Risks for the soils of the Lower Williams River watershed (Table Xc) were assigned according to the thresholds shown in Table 2.

Table 2. Acid Risk Assessment thresholds for
the Lower Williams River Assessment.

Risk	Ca:Al Molar Ratio	BSECEC
0 %	3.0+	--
<50%	1.1-2.9	--
50%	0.7-1.0	--
75%	0.5-0.6	--
>75%	0.3-0.4	<15%
100%	0.0-0.2	<15%

Table 3. The soil acidification parameters used for the acid risk assessment
of the Pottsville-derived soils in Lower Williams River watershed for the
project area by horizon. Values within a column followed by different
letters are significantly different.

Horizon	Ca:Al Ratio	BSECEC	% Risk
A	1.12 a	23.85 a	<50%
B	0.45 a	13.07 b	75%
C	0.56 a	15.15 ab	75%

Summary of Risk Assessment:
There is much uncertainty as to what the future for site productivity will be in the areas harvested. The issue is complex and difficult to predict. The time frame to be able to tell whether significant adverse effects are detrimental to soil productivity is long, several decades. However, if the thresholds presented by Cronan and Grigal (year) are applicable to field conditions, soils data from the Lower Williams River watershed indicate a high likelihood of soil productivity and consequent mortality. It is even more difficult to determine, what if any portion of future forest decline would be attributable to changes in base cation status or other soil chemistry changes from harvesting trees in the area. Other environmental factors, such as the ongoing acid deposition, drought, and disease and pests, may contribute to the success or health of the next regenerating stand.

The data do indicate that the concentrations of available base cations (especially Ca and Mg) in the soil currently are very low. Based on information about acidic deposition inputs in this region and substantial documentation in the scientific literature, leaching losses of these base cations is believed to be one of the primary explanations for their low levels. Inputs of base cations from weathering of bedrock geology are slow and the associated geologies do not have large reserves of base cations. Consequently, there is a high level of concern for the future growth of these stands, and the stands proposed for harvesting should be monitored over the long term to examine trends in growth and/or decline.

Environmental Consequences Common to All <u>Action</u> Alternatives

Soil Disturbance (Ground Disturbing Activities)
Riparian Buffer Application: The riparian buffer would act as a trapping mechanism for retaining nutrients and sediment in areas of ground disturbing activities, such as skid trail development, landing construction, and road building. Sediment travels principally in overland flow or by gravity during mechanical operations. Nutrients are transported in solution (surface and subsurface flow through the soil profile), and nutrients are also attached to soil particles and organic matter. Riparian buffers also act to protect the resources in other way which are described in detail in the Hydrology and Aquatics reports. See the Hydrology and Aquatics report to determine the width of the buffer necessary to protect the resources.

Wildlife Openings and Savannahs
Each wildlife opening would be approximately ½ to 2 acres in size and represent immediate loss of soil productivity in the short term. Immediate mitigation of this site and conversion to a wildlife opening would then reclaim soil productivity losses to some degree for the long term; however, if the site would be bladed removing the A horizon, and perhaps lower horizons, a permanent loss of soil productivity loss would result. Nutrient cycling and carbon sequestration would be altered because pasture lands have different nutrient cycles than forested areas. Effects are expected to be small and not

adverse since the openings would be a small percentage of the total project area (see Wildlife Resource Report for details and a description). These areas would receive lime and fertilizer, which would act to improve soil nutrients and base cation status. There should be regular maintenance and monitoring of these areas for soil fertility relevant to the plant species intended for wildlife forage. Grasses require a higher base cation status than trees.

In the savannah, soil productivity is expected to be altered due to the change in vegetative cover and the removal of most trees and understory vegetation. Stumps would be grubbed; therefore, soil disturbance is expected to occur in the O and A horizons as well as into the subsoil locally where root wads are removed. Extensive mixing of the soil profile would result. Liming, fertilization, and seeding should occur as part of the creation of the savannah. Soil fertility testing should be done to determine the recommended application rates for lime and fertilizer for the desired grass mixture intended for the site. There should be regular maintenance and monitoring of these areas for soil fertility relevant to the plant species intended to grow and produce wildlife forage. Grasses require a higher base cation status than trees.

Because these areas are expected to be maintained overtime with mowing and fertilization (with liming and fertilizer additions as needed), the openings are not expected to be affected substantially by base cation leaching losses from continued inputs of acid deposition. However, if maintenance does not occur, base cations leaching may occur at rates detrimental to the growth of planted grass species. The areas would be more likely to convert back to a shrub tree ecosystem.

Direct/Indirect Environmental Consequences by Alternative
Timber Harvesting Activities

Alternative 1 – No Action DIRECT AND INDIRECT EFFECTS

The **No Action Alternative** proposes no soil disturbing activities or new activities. Soils in the Lower Williams River watershed would continue to acidify at an accelerated rate due to acid deposition. Long-term vegetative responses in the watershed are unknown at this time. However, the risk assessment suggests a high probability for aluminum toxicity effects to vegetation dependent upon nutrient status in the subsoil of the soil profiles (e.g., trees). Weathering of parent materials in the lower portions of the soil profile and recycling of nutrients in the surface horizons indicate that current levels of nutrients available to feeder roots and deep roots vary by nutrient. Some ecosystem shifts from more alkaline dependent species to acid dependent species may occur and be driven by continued input of acid compounds from the atmosphere.

The comparison of alternatives are based on both short term and long term effects both within the activity area (which varies by alternative – see the Soil Productivity report) and the project area which is 14,400 acres.

Table 4. Short term and long term effects of the Alternative for the Lower Williams River Project Area.

	SHORT TERM EFFECTS	LONG-TERM EFFECTS
NO ACTION – ALT1 Soil Disturbance (acres)	0	0
Percent of Activity Area	0	0
Percent of Project Area	0	0
Removal of Timber volume CCF	0	
Proposed Action – ALT2 Soil Disturbance (acres)	225	158
Percent of Activity Area	11.8	8.3
Percent of Project Area	1.6	1.1
Removal of Timber volume CCF	29,414	
Alternative 3 Soil Disturbance (acres)	143	101
Percent of Activity Area	8.5	6.0
Percent of Project Area	1	0.7
Removal of Timber volume CCF	26,221	
Soil and Water – ALT4 Soil Disturbance (acres)	57	34
Percent of Activity Area	3.5	2.1
Percent of Project Area	0.4	0.2
Removal of Timber volume CCF	23,426	
All Helicopter – ALT5 Soil Disturbance (acres)	35	18
Percent of Activity Area	2.2	1.1

Table 4. Short term and long term effects of the Alternative for the Lower Williams River Project Area.		
	SHORT TERM EFFECTS	LONG-TERM EFFECTS
Percent of Project Area	0.2	0.1
Removal of Timber volume CCF	21,707	

The results of the soil chemistry monitoring project indicate these soils have high risk for future failure for regeneration of marketable timber based on the chemistry in the B horizon. With harvesting and organic matter removal, base cations are removed from the system, causing these soils to become more acidified. Therefore, there is concern that the forest stands may not regenerate a valuable timber stand, and this could occur whether the stands are harvested or left unharvested to regenerate naturally. There is no evidence that the current stand was affected by acidification effects at the time it last regenerated -- past timber harvesting has been conducted in the project area over the last thirty years. Those stands are well stocked with high value timber species (Bard, J. Personal Communication 2007; MNF CDS database 2005).

For all alternatives, tops and limbs would be left on the ground and allowed to decompose and return nutrients back into the soil profile. Whole tree harvesting is not permitted on the Forest where soil inventories determine the need for on-site nutrient retention (Forest Plan Standard TR05 pg. II-40, 2006.) However, leaving tops and limbs alone would only lessen the amount of base cations leaving the site post harvest. This would still result in an overall loss of base cations from within the stand harvested which is a direct effect and could be long term as long as acid deposition rates continue in the future, even if deposition levels are reduced.

Erosion prevention measures would be utilized to prevent or control the movement of sediment off disturbed areas. This would help to further retain nutrients within the subwatershed and help maintain soil productivity within the treatment units and the subwatershed.

Stem-only or saw log harvesting typically done in the central Appalachians would be less deleterious to high risk sites if helicopter or skyline logging were used instead of conventional ground skidding. Helicopter logging would result in greater organic material and nutrients retention on site and less soil disturbance. Erosion and associated nutrient losses, subsequently, would be expected to be lower. On average, helicopter and skyline logging disturb only 2.5% of a site compared to approximately 20-25% for conventional harvest methods (Grigal 2000).

Short harvest rotations decrease base cation availabilities in soils due to shorter times for organic matter accumulation via leaf and litter fall (Blanco et al. 2005; Grigal 2000).

Because the Lower Williams River watershed soils have low base cation concentrations, the longest reasonable harvest rotation should be employed to allow base cations to be replenished to the extent possible by litter accumulation and weathering.

COMPARISON OF ALTERNATIVES

In the following comparison of alternatives several factors are considered and listed in the order of importance – starting with the most important factor: 1) the amount of soil disturbance per alternative, 2) the method of harvesting, 3) the silviculture prescriptions assigned, and 4) the volume of timber being harvest. See the discussion above for relative numbers and values assigned to each factor per alternative. The amount of soil disturbance is directly related to the method of timber harvest. Maintaining the O and A horizons intact as much as possible would help to alleviate nutrient losses from timber harvesting (Hallett 1997.)   Helicopter harvesting of timber is the least soil disturbing method resulting in an average soil disturbance of less than 3 percent, although the landings are larger than most conventional logging landings. Traditional ground based operations can disturb a range of area within a unit, depending upon slope, topography, operator equipment limitations, safety concerns, available cable or dragline, and other factors such as existing skid systems and width of skid roads. Prescriptions such as shelterwoods and two-age cuts remove high percentages of basal area from a stand; whereas, thinning removes much less basal area (depending on the objective and species composition desired). Volume is dependent upon stand composition and age. This is usually a constant for each stand by alternative (meaning prescriptions do not change by alternative) and depends upon the final selection of stands defined in each alternative for harvest. In summary, the more ground disturbance, the more acres of even-aged management, and/or the more volume removed from an area, the greater the risk for adverse effects to future regenerating stands.

The risk is defined as the ability of a stand to regenerate itself to a level of equal site productivity and similar desirable species composition as the stand that was harvested. Risk is elevated by the factors discussed above and continual inputs of acidic deposition and consequent effects described in the air quality section, as well as the cumulative nature of acid deposition effects described in the CUMULATIVE EFFECTS (Section below.)

In the context of harvesting timber on acid sensitive soils and the effects that harvesting has on potentially further depleting the soil of base cations, the ranking of Alternatives is: Alternative 1 < Alternative 5 < Alternative 4 < Alternative 3 < Alternative 2 for having adverse effects to the soil resource, specifically base cation loss from timber harvesting activities and other associated ground disturbing activities.

CUMULATIVE EFFECTS

Acid Deposition and Cumulative Effects: Acid deposition occurs within the project area and watershed independent of Forest Service management as described in the EXISTING CONDITION. Soil acidification occurs naturally as a consequence of soil formation in the Appalachians. However under the effects of acid deposition, soil acidification occurs at an accelerated rate. The cumulative effect for further soil

acidification within the project area is further considered under proposed management activities, specifically timber harvesting and associated activities for the Lower Williams project area.

The risk assessment described under the N**o Action Alternative 1** of the soils in the watershed can lead to management implications and recommendations that the Forest Service would want to consider in the **Action Alternatives**. For example, timber harvesting practices can be modified to take into account areas with low Ca:Al molar ratios. Harvest methods affect the nutrient cycling of the forest floor differently (Elliott and Knoepp 2005). Methods, such as whole-tree harvesting, that remove extensive amounts of organic material have more detrimental effects on nutrient availability than stem-only harvesting, which retains organic material (branches, leaves, tree crowns) on the harvest site (Elliott and Knoepp 2005). Short harvest rotations also decrease soil base cations due to reduced accumulations of organic matter and higher soil disturbance (Grigal, 2000). Likewise, soil disturbing activities, including skidding and log yarding, decrease soil productivity by removing soil organic matter and compacting soil (Berger et al., 2004). Thus, the Ca:Al molar ratio can be used to guide the placement of soil disturbing activities and determine harvest method and rotation length.

Ultimately the significant adverse effects are seen cumulatively in soil acidification through the combination of the existing condition caused by current and historic acid deposition inputs, the additional effects of timber harvesting activities, the future predictions of acid deposition inputs, and the presence of geologies that are low in base cations and provide input through slow weathering. This is all despite overall efforts to reduce emission rates by federal policies, implement more sensitive logging methods that produce less soil disturbance and extending rotation ages.

<u>Future Actions: Terrestrial Liming</u>
The concept of liming forests has been studied for almost fifty years (Long et al. 1997.) There are only three well documented retrospective studies of effects from terrestrial liming on vegetation and soils: the USFS Sugar Maple research group -- Long (1997); the Hubbard Brook wollastonite nutrient addition -- posted on the Hubbard Brook Experimental Forest website (provide website address here); and the Canadian group liming study -- Moore et al. (2000,2006). The Sugar Maple and Canadian groups used dolomitic lime, and showed that liming positively benefited tree growth and soil chemistry ten years following application. However, Long et al. (1997) provide sideboards for liming that require application rates that may be higher than needed to see a response in soil chemistry alone. Moore et al. (2006) were more aggressive in their recommendations and suggested that if mitigations such as liming do not occur in some sites, decline and mortality would occur as a result of continuing acid deposition and soil acidification.

Soil liming may be warranted in locations where Ca:Al ratios denote high risk but where harvesting is necessary to meet land owner desires. The benefits of liming acid, agricultural soils are well known (Skousen and McDonald 2005). Liming increases Ca concentrations, neutralizes the acidity, and decreases Al toxicity in acid soils. Some

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research indicates that dolomitic limestone is the most effective type of liming material for forest soils, but results have been mixed. For example, liming can increase organic carbon and N leaching from the soil due to increased microbial activity (Rengel 2003), thereby negating some of the positive effects of liming. Some lime materials are more suited for spreading in forests, and coarse limestone sands have been more cost efficient than pelletized lime (Mizel 2005). Some detrimental effects of liming forest soils have been noted in these studies as well, and these need to be thoroughly considered prior to implementing liming.

Unavoidable Adverse Impacts

Timber harvesting activities would occur on approximately 1900 acres of soils sensitive to acid deposition. Given the existing condition of the soil base cation status, this timber harvest has a high risk of resulting in unavoidable adverse impacts to the soil resource by further acidifying the soil and resulting in soil productivity decline and potential site productivity decline.

Irreversible or Irretrievable Commitment of Resources

See the Soil Productivity Report. It may be argued that timber harvest on these soil types would remove calcium and magnesium from the site that would not be replaced to the site because of 1) the historic, current, and future rates of acid deposition and subsequent leaching of base cations from the soil profile and 2) the existing base poor geology which weathers and replenishes limited amounts of calcium and magnesium to the soil.

Consistency with the Forest Plan

All alternatives described are done so under the direction of Forest Plan goals, objectives, guidelines, and standards for the soil resource.

Consistency with Laws, Regulations, and Handbooks

All alternatives would be implemented consistent with Forest Service laws, regulations, and handbooks regarding management of the soil resource.